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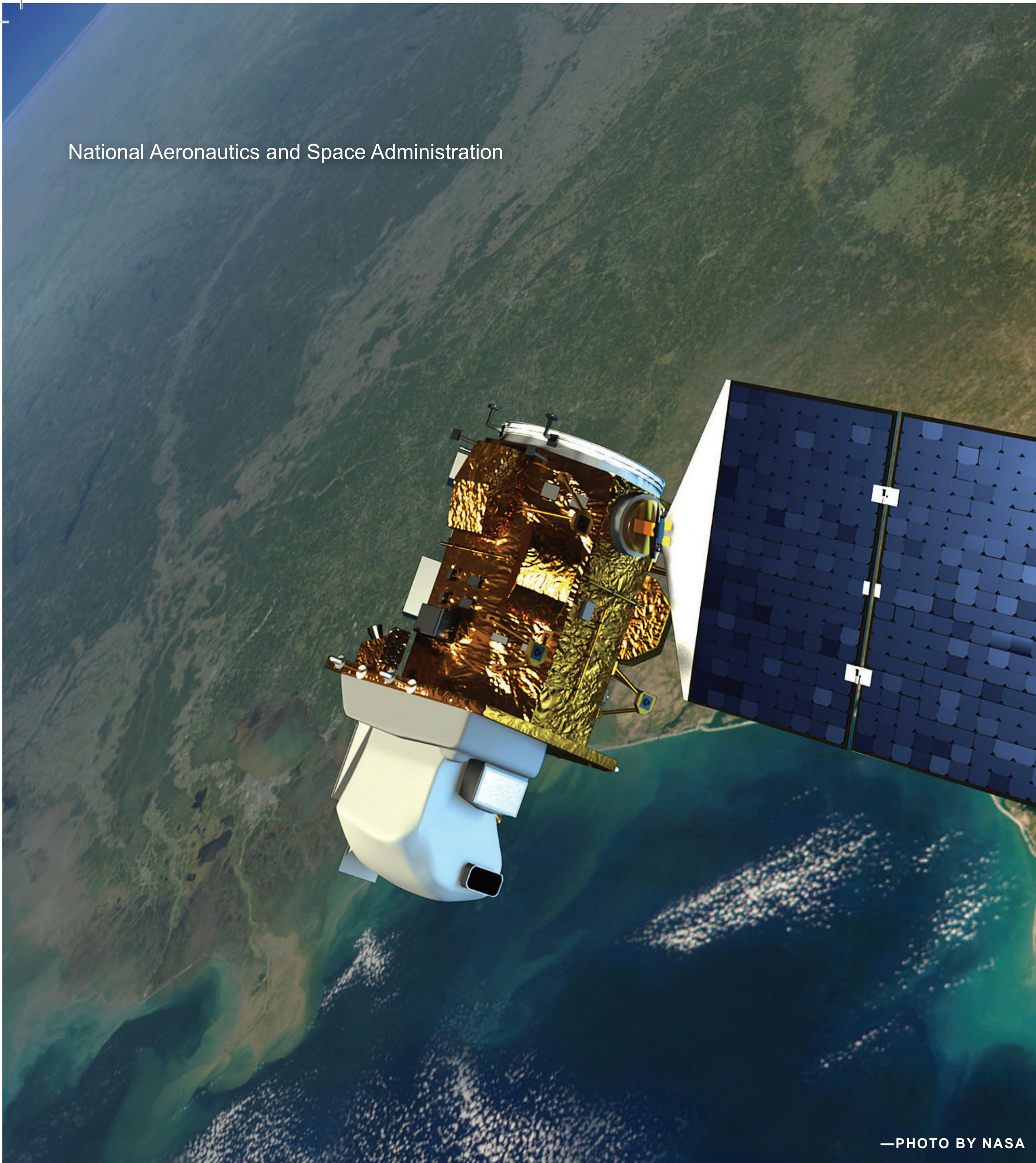

—PHOTO BY NASA

Landsat Data Continuity Mission (LDCM)

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Nona Cheeks

[FROM THE *Chief*

From the Chief

Landsat represents a highly visible and compelling success story, both for NASA in general and NASA Goddard Space Flight Center in particular. Since the launch of Landsat 1 in 1972, this ongoing program has provided an incomparable wealth of data about the land surface of our planet. A complete review of all the benefits Landsat has provided to humanity over the years would require far more space than we have available to us here; a few examples include climate research, environmental monitoring, agriculture, and disaster recovery just to name a few.

The Landsat Data Continuity Mission (LDCM) is the latest satellite in the Landsat series. Successfully launched on February 11, 2013, LDCM – which is now known throughout the world as Landsat 8 – carries onboard two primary instruments, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The former observes the Earth in visible light, while the latter operates in the infrared. These instruments significantly enhance Landsat's ability to collect and process vast amounts of high-quality data. Landsat 8, along with the still-operational Landsat 7, ensures that Landsat continues to provide high value to society as the program enters its fifth decade of service.

This issue of *Tech Transfer News* discusses several important aspects of NASA Goddard's role in Landsat. We present a brief overview of LDCM/Landsat 8; and interview two members of the team, Dr. James Irons (Associate Deputy Director for Atmospheres, Earth Sciences Division) and Dr. Murzy Jhabvala (Chief Engineer, Instrument Systems and Technology Division). Dr. Irons and Dr. Jhabvala speak with us about their roles during the development of the LDCM mission. We then examine several technologies developed specifically for LDCM/Landsat 8, and how they could be leveraged into potential terrestrial applications. In a separate article, we look at the many ways Landsat data has been used, both for scientific research and to establish new commercial markets. And we discuss how the SBIR/STTR programs played a role in the development of Landsat technologies, and also review a few recent news items involving LDCM/Landsat 8.

In addition, our regular duo of legal experts, attorneys Bryan Geurts (Chief Patent Counsel for NASA Goddard's Office of Patent Counsel) and Erika Arner (Partner for the law firm Finnegan, Henderson, Farabow, Garrett & Dunner) offer their respective viewpoints on how the America Invents Act has been implemented and how it has already affected the patenting landscape within the U.S. This is a highly relevant and timely topic with important implications for all innovators within NASA Goddard and beyond.

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[LANDSAT DATA *Continuity Mission*

Data Continuity Mission

▶ *Landsat Data Continuity Mission (Landsat 8).*

—PHOTO BY NASA

The Landsat program encompasses a series of Earth-observing satellite missions jointly managed by NASA and the United States Geological Survey (USGS). Beginning with the launch of Landsat 1 in 1972, the program represents the longest continuously running record of changes on the surface of our planet as observed from a space-based platform. Landsat recently celebrated its 41st anniversary of ongoing operation, providing critical data for applications as diverse as energy and water management, forest monitoring, human and environmental health, urban planning, disaster recovery, agriculture, and many others.

The Landsat Data Continuity Mission (LDCM) is the eighth in the Landsat program. LDCM (which upon three months after its launch earlier this year was renamed Landsat 8) incorporates cutting-edge technologies for capturing detailed Earth surface features across a wide spectrum of visible and infrared bands. Together with the still-operational Landsat 7, these two satellites observe every spot on the globe at least once every eight days.

LDCM/Landsat 8 carries two primary instruments, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). These instruments work together to record terrestrial surface features in the visible, near infrared, shortwave infrared, and thermal infrared wavelengths. OLI provides two new spectral bands, one tailored especially for detecting cirrus clouds and the other for coastal zone observations. TIRS collects data for two additional narrow spectral bands in the thermal region, formerly covered by only one wide spectral band on previous Landsat missions, to measure Earth's thermal energy.

LDCM Operational Land Imager (OLI).

—PHOTO BY NASA

Operational Land Imager (OLI)

The OLI observes Earth in the visible, near infrared, and shortwave infrared portions of the spectrum, providing images with spatial resolutions of 15 meters (panchromatic) and 30 meters (multi-spectral) along a 185 km wide swath of the Earth's surface. This allows researchers to clearly distinguish features such as urban centers, farms, forests, and other topographies.

The OLI instrument represents a significant enhancement over previous Landsat missions. It takes advantage of a technological approach pioneered by NASA's experimental EO-1 satellite. To provide better land surface data while simultaneously reducing the moving parts required for the hardware, OLI incorporates a design that uses long detector arrays, with over 7,000 detectors per spectral band, aligned across its focal plane to view across the swath. This will deliver more reliable data with higher signal-to-noise ratio.

Thermal Infrared Sensor (TIRS)

TIRS measures land surface temperature in two thermal bands, incorporating a novel technology known as quantum well infrared photodetectors (QWIP) that employs complex quantum mechanics physics to detect heat. QWIP arrays offer a new, lower-cost alternative to conventional infrared technology. TIRS uses QWIP detectors to record thermal infrared radiation emitted by the Earth whose intensity depends on surface temperature. These wavelengths, called thermal infrared, are well beyond the range of human vision. The QWIP detectors that TIRS uses are sensitive to two thermal infrared wavelength bands, allowing the instrument to separate the temperature of the Earth's surface from that of the atmosphere.

TIRS is especially valuable to water resource managers who rely on its highly accurate measurements to track how land and water are being used. For example, in the western U.S. states, where nearly 80% of available fresh water is used to irrigate crops, TIRS provides an invaluable tool for managing water consumption.

TIRS provides a 185 km field of view, with a spatial resolution of 100 meters. This is sufficient for critical applications such as measuring water consumption over fields that use center-pivot irrigation.

Landsat 8 in action

LDCM was successfully launched on February 11, 2013; and after three months of operation was renamed Landsat 8. The data collected by the mission's OLI and TIRS instruments is now available to download at no charge from GloVis, EarthExplorer, or via the LandsatLook Viewer. This data is processed to be consistent with archived data from previous Landsat missions. Data products will be delivered as 16-bit images.

The OLI and TIRS sensors deliver improved signal-to-noise performance quantized over a 12-bit dynamic range. This translates into 4096 potential grey levels in an image (compared with 256 grey levels in previous 8-bit instruments). This provides enhanced characterization of land cover state and condition.

Although it has only been in operation a short time, Landsat 8 has already proved itself a worthy successor to its predecessors, continuing the program's critical role in monitoring, understanding, and managing the resources needed to ensure the quality of human life on Earth. Its ongoing contributions to Landsat's already vast database of Earth Science data will be essential to numerous applications and programs dedicated to the public's well-being, resulting in incalculable benefits to the United States and world economy.

[APPLICATIONS *for Landsat Data*

Applications

In its four decades of existence, the Landsat program has compiled a vast database of Earth phenomena. This represents a comprehensive archive of data for every location on our planet's continental, coastal, island, and near-polar surfaces. This data allows researchers to perform a wide array of analyses that allow them to examine current conditions on Earth in a variety of ways. Equally important, Landsat offers an unprecedented view into the changes that have occurred during the past 41 years (and counting). Changes observed over the duration of the Landsat program provides scientists with opportunities for modeling and prediction, allowing us to better anticipate and prepare for the possible effects of climate change and global warming and their impacts on weather, the environment, and human health.

Landsat data is used by countries across the globe. At present, the Landsat program downloads data directly to a number of ground stations located in or outside the U.S. The table on pages 6-7 lists some of the uses to which Landsat data has been applied.

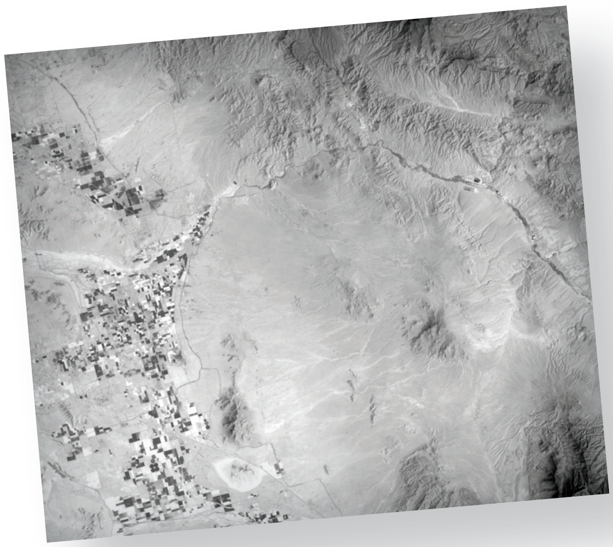
The importance of Landsat data to climate scientists and researchers is obvious, as is its utility in disaster recovery and analysis. Perhaps less obvious (but still important) is Landsat's value to commercial enterprise, in industries as diverse as agriculture, commodity investment, health care, and insurance. These represent significant revenue opportunities and an emerging market for enterprising companies who can leverage this data and create data products and reports aimed at specific consumers.

In this article, we briefly look at a few of the many innovative ways Landsat data is being used by other government agencies, non-U.S. governments, researchers, and commercial companies.

Managing resources

Originally, the primary use of Landsat data was to explore the value of Earth observations from space. Since that time, Uses for this data have expanded into many other natural science fields, such as agriculture, forestry, land use, water resources, and natural resource exploration. In addition, Landsat now provides critical data for areas associated with human activity, including human population census, growth of global urbanization, and depletion of coastal wetlands. This has helped guide nations to adopt a safe and informed approach to development.

Landsat imagery is now essential for helping ensure the well-being of communities around the globe. This information allows agricultural planners to evaluate productivity and forecast crop yields, thereby ensuring a plentiful food supply for local populations – or just as critically, quickly identifying potential shortfalls in time to enact preventive measures.



▶ *Landsat 8 infrared image of the Phoenix, Arizona area, captured with the TIRS instrument. Cooler areas appear darker; warmer areas are brighter..*

—PHOTO BY NASA

AGRICULTURE, FORESTRY AND RANGE RESOURCES	LAND USE AND MAPPING	GEOLOGY	HYDROLOGY	COASTAL RESOURCES	ENVIRONMENTAL MONITORING
Discriminating vegetative, crop and timber types	*Classifying land uses*	*Mapping major geologic features*	*Determining water boundaries and surface water areas*	*Determining patterns and extent of turbidity*	*Monitoring deforestation*
Measuring crop and timber acreage	*Cartographic mapping and map updating*	*Revising geologic maps*	*Mapping floods and flood plain characteristics*	*Mapping shoreline changes*	*Monitoring volcanic flow activity*
Precision farming land management	*Categorizing land capabilities*	*Recognizing and classifying certain rock types*	*Determining area extent of snow and ice coverage*	*Mapping shoals, reefs and shallow areas*	*Mapping and monitoring water pollution*
Monitoring crop and forest harvests	*Monitoring urban growth*	*Delineating unconsolidated rocks and soils*	*Measuring changes and extent of glacial features*	*Mapping and monitoring sea ice in shipping lanes*	*Determining effects of natural disasters*
Determining range readiness, biomass and health	*Aiding regional planning*	*Mapping volcanic surface deposits*	*Measuring turbidity and sediment patterns*	*Tracking beach erosion and flooding*	*Assessing drought impact*
Determining soil conditions and associations	*Mapping transportation networks*	*Mapping geologic landforms*	*Delineating irrigated fields*	*Monitoring coral reef health*	*Tracking oil spills*
Monitoring desert blooms	*Mapping land-water boundaries*	*Identifying indicators of mineral and petroleum resources*	*Monitoring lake inventories and health*	*Determining coastal circulation patterns*	*Assessing and monitoring grass and forest fires*
Assessing wildlife habitat	*Citing transportation and power transmission routes*	*Determining regional geologic structures*	*Estimating snow melt runoff*	*Measuring sea surface temperature*	*Mapping and monitoring lake eutrophication*
Characterizing forest range vegetation	*Planning solid waste disposal sites, power plants and other industries*	*Producing geomorphic maps*	*Characterizing tropical rainfall*	*Monitoring and tracking 'red' tides*	*Monitoring mine waste pollution*
Monitoring and mapping insect infestations	*Mapping and managing flood plains*	*Mapping impact craters*	*Mapping watersheds*	*Coral reef health assessment*	*Monitoring volcanic ash plumes*
Monitoring irrigation practices	*Tracking socioeconomic impacts on land use*	*Chevron discovery*	*Mapping closed-basin ponds*	*Global coral reef mapping*	*Assessing carbon stocks*
Bison management	*Online mapping*	*Mega-lake discovery*	*Monitoring wetlands*	*Chesapeake Bay restoration*	*Cancer research*
Crop production estimates	*Cartographic discoveries*	*Soil carbon flux*	*Water management*	*Monitoring coastal erosion*	*Atmospheric modeling*
Quantifying burn severity	*Mapping Antarctica*	---	*Wetland restoration*	*Coastal Studies*	*Mapping Rift Valley Fever risk areas*

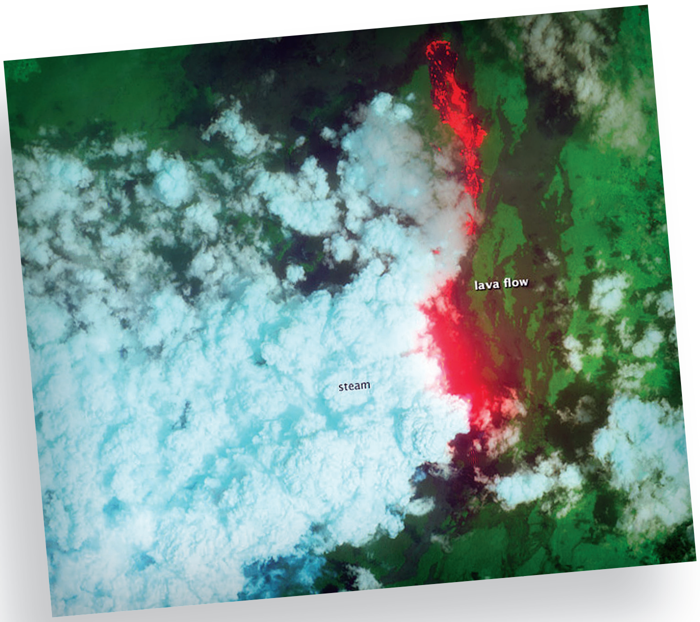
AGRICULTURE, FORESTRY AND RANGE RESOURCES	LAND USE AND MAPPING	GEOLOGY	HYDROLOGY	COASTAL RESOURCES	ENVIRONMENTAL MONITORING
Fighting crop insurance fraud	*Fighting hunger*	---	*Monitoring dam construction*	*Chesapeake Bay management*	*Assessing clear-cutting impacts*
Forest trends in Madagascar	*Urban sprawl and climate change*	---	*Groundwater discharge*	---	*Assessing impacts of industrial logging*
Forest protection in Peru	*Caribbean Island mapping*	---	*Bushfire impact on water yields*	---	*Mapping urban heat islands*
Better Estimate of Boreal Forest Loss	*Tropical forest clearing for development*	---	---	---	*Landsat, Potholes, and Climate Change*
Crop water stress	*Exploring ancient Mexico*	---	---	---	*Disaster aftermath*
Crop water demand	*Landsat Image Mosaic of Antarctica*	---	---	---	*African environmental change*
Rice production monitoring	*Kansas Map*	---	---	---	*Cyclone Nargis' impact on Burma*
Demise of Papua New Guinea forests	---	---	---	---	*Fire prevention in Spain*
Monitoring conservation tillage	---	---	---	---	*Surveying mangroves*
North American forest disturbance	---	---	---	---	*Greek fires*
Sumatran deforestation	---	---	---	---	*Algae monitoring*
Forest damage caused by Hurricane Katrina	---	---	---	---	*Glacier monitoring*

Landsat climate data and human health

Landsat provides a unique opportunity to study climate change over an extended period of time. This makes possible research into the effects of climate change on human health, an area of increasing interest in recent years. To help facilitate our understanding of how climate change affects human health, agencies such as the U.S. Centers of Disease Control and Prevention (CDC) are promoting initiatives to help public health departments and others understand and plan for the long-term health effects of global warming. For instance, the CDC's Building Resilience Against Climate Effects (BRACE) framework:

"…is a five step process that enables a health department to incorporate the best available atmospheric science into a process designed to improve the quality of inputs and assumptions made during the traditional planning process, and supports the development and implementation of a unified climate and health adaptation strategy for a jurisdiction." [1]

[1] "CDC's Building Resilience Against Climate Effects (BRACE) Framework," U.S. Centers for Disease Control and Prevention web site, http://www.cdc.gov/climateandhealth/BRACE.htm.



▶ *Landsat 8 image of Nyamuragira volcano.*

—PHOTO BY NASA

A better understanding of the health risks associated with climate change will also be very valuable to healthcare providers and insurers. Providers will be able to help plan and staff for long-term increases in certain heat-related health conditions, while insurers can use this data to assess risks and reduce costs. Key stakeholders in this market include:

- Potential users in the public health and healthcare communities.
- Climate scientists who can analyze the historical climatological record and project future climate changes and conditions.
- Medical scientists who can accurately assess the effects climate conditions will likely have on human health.
- Government agencies such as the CDC who are actively promoting awareness of the climate change/human health connection through programs such as BRACE.

Landsat data can serve each of these communities, both directly and via value-added data products prepared by third-party developers. This latter group may represent a nascent market opportunity that could grow significantly as the effects of global warming – and what the world needs to do to address them – become increasingly foremost in the public's minds.

Disaster recovery

Although Landsat data does not provide the up-to-the-minute data required for real-time disaster monitoring and response; it can nonetheless help facilitate disaster aid and recovery. One example is forest fire management. By providing "before and after" images of areas affected by burning, Landsat generated maps can help guide emergency recovery teams to mitigate damage and stabilize at-risk landscapes.

Another Landsat application is monitoring volcano activity. For example, Landsat 8 recently captured images of an eruption on Mount Nyamuragira in the Republic of Congo, one of the country's most active volcanos.

Anywhere a major disaster occurs, Landsat can provide imagery that allows governments to assess the disaster's impact and respond appropriately.

Commercial applications

As we noted earlier in this article, climate change data provided by Landsat could be of high value to health care professionals, to help plan for the potential effects these changes will have on human health. In addition, data about the effects of climate change could also be useful for applications not directly within the medical community. For instance, climate change will likely have serious implications for builders, architects, and property insurers.

Landsat data is also of commercial importance to companies associated with forestry. The wood and paper industries have expressed interest in supporting future Landsat missions. In addition, the USDA Foreign Agriculture Services uses Landsat data to develop its global commodities forecast; which is then made available to investors in agricultural-related businesses and markets.

Landsat data: Benefiting all residents of Earth

This brief article has touched upon only a few of the many applications to which Landsat data has been applied. As the table in the beginning of the article demonstrates, there are many other ways in which Landsat data can provide highly critical guidance that helps improve the quality of life on Earth, in ways that in many instances saves lives. And while Landsat's database is made readily and freely available to all, it remains of high value to commercial applications in many diverse industries. The Landsat program therefore represents a highly visible success story that clearly demonstrates how investment in space science can benefit everyday life for virtually every citizen on planet Earth.

Landsat 8

[INTERVIEW WITH Dr. James Irons and Dr. Murzy Jhabvala

Interview

The Landsat program represents a long-term effort to monitor changes on the surface of the Earth. The latest Landsat mission is the Landsat Data Continuity Mission (LDCM), which was renamed Landsat 8 following launch and in-orbit commissioning. Along with the still-operational Landsat 7, this mission continues to provide high-quality data used in a wide variety of ways by academia, government agencies, and commercial interests.

In this interview we speak with two key members of the LDCM team, Dr. James Irons (Associate Deputy Director for Atmospheres, Earth Sciences Division) and Dr. Murzy Jhabvala (Chief Engineer, Instrument Systems and Technology Division). Dr. Irons served as Project Scientist for LDCM; while Dr. Jhabvala played an important role in the development of the focal plane for LDCM's Thermal Infrared Sensor (TIRS) instrument.

Q. *Can you provide a little background of Landsat and how LDCM fits in?*

Dr. James Irons, Associate Deputy Director for Atmospheres, Earth Sciences Division: Landsat is an interagency program conducted jointly by NASA and the U.S. Geological Survey, operating within the Department of the Interior. Landsat 1 was the first non-weather civilian satellite created for observing the surface of the Earth. Since then there have been seven subsequent Landsats launched; with at least one and sometimes two in operation at any given time. These have provided continuous images of Earth, allowing us to monitor change over the past four decades. We reached the 41st anniversary of the Landsat 1 launch on July 23, 2013.

LDCM is the eighth Landsat mission. NASA was responsible for building the space component of the mission, and launching it into orbit. The USGS provides the ground system, and assumed the lead in satellite operations, data collection, and archiving. Once the satellite was launched and the USGS took control, LDCM was renamed Landsat 8, the name by which it is known today.

Q. *What instruments are onboard LDCM/Landsat 8?*

Dr. Murzy Jhabvala, Chief Engineer, Instrument Systems and Technology Division: Two instruments were developed for LDCM. One is the Operational Land Imager (OLI), and the other is the Thermal Infrared Sensor (TIRS) instrument. The

▶ *Assembling the TIRS instrument.*

—PHOTO BY NASA

TIRS instrument requires infrared detectors. Other key instrument components include the telescope optics, cryo-coolers, mechanical subsystems and electrical systems. My role was to lead the development of the infrared focal plane for TIRS, incorporating a new class of infrared detection technology based on quantum well infrared photodetectors or "QWIP" for short.

Q. *How did you become involved with LDCM?*

Dr. Murzy Jhabvala: The original choice for the LDCM was a microbolometer-based instrument; this was pursued for several years. However, during development the LDCM team identified issues with the microbolometer approach, problems that could not be satisfactorily addressed within schedule. As a result, the detector originally being developed for TIRS did not meet requirements. At one point, the team seriously considered not including an infrared detector on LDCM at all. Meanwhile, the development of LDCM with the OLI instrument continued on without interruption.

I have been working with QWIP technology for approximately 20 years. This technology hadn't been considered for LCDM before, since it was seen as relatively immature – for example, we didn't yet have sufficient data on the longwave, broadband performance of QWIP detector arrays. However, LDCM development was in a critical stage due to the failure of the microbolometer. So in 2008 the LDCM team asked us about our work with QWIP technology. We proposed a scenario for them to consider, and they decided to take a chance.

One challenge was the schedule; we had to develop the detector arrays and entire focal plane assembly within two years. This included design, fabrication, vibration testing, flight qualification – it was essentially a fire drill for the entire time. We ended up building and characterizing the QWIP–based focal plane within 18 months, with everything working as conceived.

Dr. James Irons: I'd like to add that for the past two Landsat missions, including LDCM, we've tended to look for technologies with high TRL levels. QWIP was an exception, because the short schedule necessitated our accepting a certain level of risk. Fortunately, Murzy could work very quickly to meet our needs – it was the only reason we could get TIRS done in time. QWIP was a critical contribution to LDCM, and it came through like gangbusters. Usually components that operate in the focal plane are the most challenging. But thanks to Murzy, in this case it turned out to be the smoothest part of the whole project.

Murzy Jhabvala

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Education: BS Engineering Science, University of Rhode Island, 1973. MS Electrical Engineering, Northwestern University, 1974.
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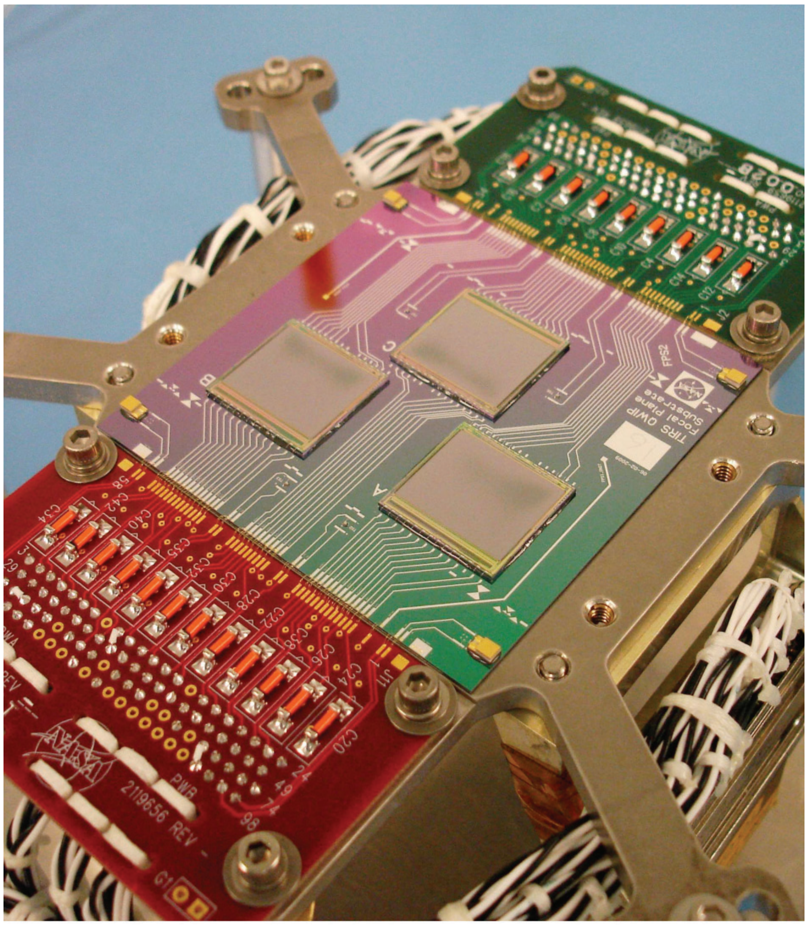


TIRS focal plane assembly containing the three QWIP arrays. All components shown in this image were developed specifically for LDCM.

—PHOTO BY NASA

Q. *How did you overcome the accelerated schedule?*

Dr. Murzy Jhabvala: To help make up for the lack of time, we had different groups working on various components of the QWIP detector. In addition to our team at NASA Goddard, the Army Research Laboratory was involved in the development. A private company called QmagiQ also played a major role, along with participation from Thales Research and Technology. NASA Goddard and the Army Research Lab fabricated a QWIP array based on a corrugated light coupling mechanism, while QmagiQ and Thales built arrays based on a grating light coupling mechanism structure. Having multiple groups working on different array designs helped minimize risk. This collaborative and extremely interactive environment was absolutely essential to the success of this project.

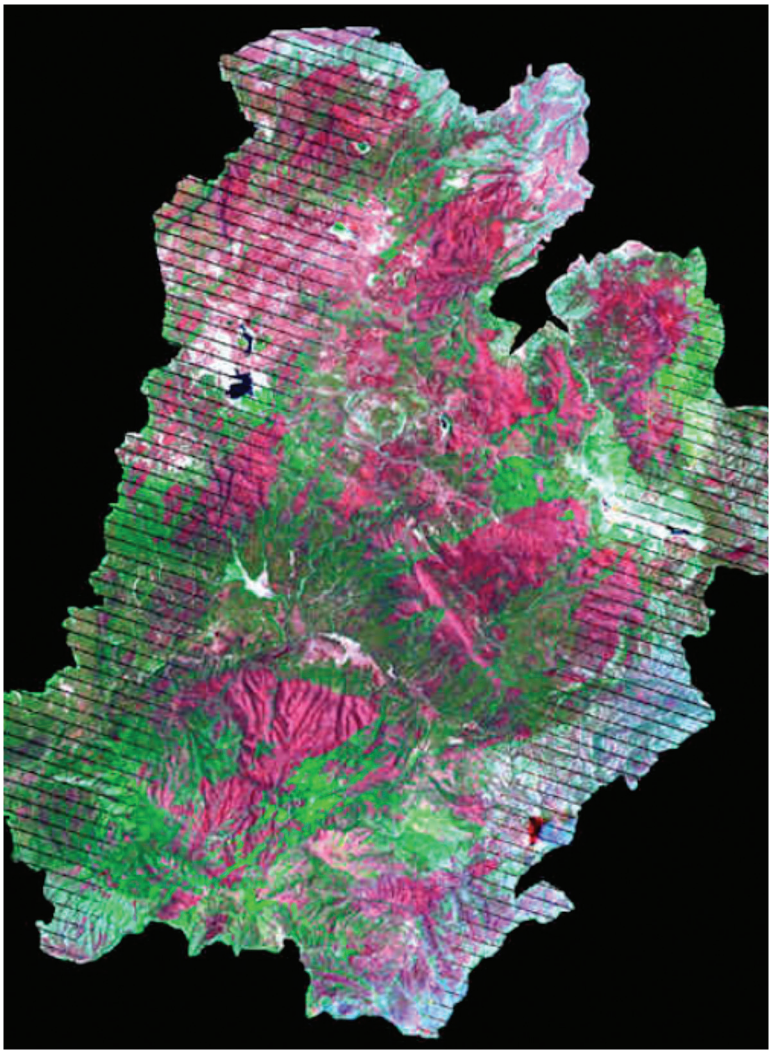
We originally worked with QmagiQ under a Small Business Innovative Research (SBIR) grant to develop a QWIP–based infrared camera. This helped convince the LDCM team that the QWIP approach could work. We then approached QmagiQ and asked them to make QWIP arrays for us, working under a Space Act Agreement. To meet the accelerated schedule, we had to parse out the work.

The QWIP technology produces an excellent detector; reliable, stable, and uniform. It's also relatively cheap and easy to fabricate in a high-technology context.

Q. *Does QWIP have potential applications outside Landsat?*

Dr. Murzy Jhabvala: As I mentioned earlier, I have been working on QWIP for around 20 years or so. Initially it was considered something of a novelty. Then I presented our work at a NASA sponsored Technology Transfer conference and demonstrated it to people who started suggesting all kinds of applications for QWIP, applications we'd never thought about. I keep a running list of all the suggested applications, which continues to grow.

A student at MIT, Zoe Szajnfarber, wrote a thesis paper that tracks the evolution of QWIP. It's an excellent summary of the history of QWIP and its potential applications. *(See "Quantum Well Infrared Photodetector Innovation Pathway," on the George Washington University web site at http://www.seas.gwu.edu/~zszajnfa/docs/QWIP%20pathway.pdf.)*



▶ *Landsat 7 image of a forest fire in Arizona. Purple represents heavily burned areas.*

—PHOTO BY NASA

Q. *Getting back to the Landsat mission itself, how is the data provided by Landsat used?*

Dr. James Irons: Landsat data is archived in a USGS facility in Sioux Falls, South Dakota. This archive is then made available to anyone who has an application for it. These include a broad and diverse variety of science and resource applications relating to changes on the Earth's surface. Examples include forest monitoring, urban development and growth, and changes to glaciers and polar sea ice. The data is also used to monitor acreage for agricultural production. Another application is water management, which is especially critical in U.S. Range land, snowpack – these and other surface features can be monitored in real-time.

Every point on Earth is within view at least once every 16 days, or every 8 days when there are two Landsats in operation, as is currently the case.

Q. *Can Landsat be used in disaster situations?*

Dr. James Irons: Landsat data really isn't intended for disaster monitoring and response, but it can play a critical role in disaster aid and recovery. For example, Landsat data has been used to compile severity maps in burn areas. These maps help guide emergency recovery teams to mitigate damage and stabilize slopes. Anywhere a major disaster occurs, the Landsat archive can provide "before and after" data that allows us to assess the impact.

This data is used internationally. Currently, Landsat data is directly downloaded to some 15 to 20 ground stations located outside the U.S.

Q. *Can Landsat data be used commercially?*

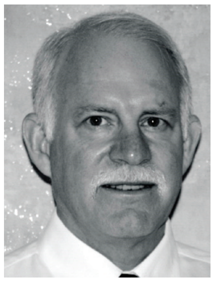
Dr. James Irons: Landsat data does indeed have commercial applications. I recently had an email exchange with a colleague from Virginia Tech, discussing how the forestry industry can use this data to help manage timber resources. The wood and paper industries are now interested in supporting future Landsat missions. The USDA Foreign Agriculture Services uses Landsat data to develop its global commodities forecast, which is used by investors. The forecast is available via subscription; a copy is sent directly to the Commodities Exchange in Chicago.

Landsat also provides imagery used by Google Earth. Large-scale Google Earth images are based on Landsat data. If you are viewing an image covering 50 to several hundred miles across in Google Earth, chances are you are looking at Landsat data.

Q. *Have Landsat technologies helped the commercial sector in other ways?*

Dr. James Irons: An early innovation created for Landsat 1 was whisk-broom scanning, also called electromechanical scanning. This allows Landsat to collect digital images without employing a shutter; instead the system employs an oscillating mirror that sweeps the field of view. Landsat established whisk-broom scanning as a viable technology; and it was used on all subsequent Landsats up to Landsat 8, which uses long arrays of detectors across the focal plane.

It's important to note that Landsat itself has created a new industry. In the beginning, the first satellites observing the Earth from space were weather and military instruments. Landsat was the first non-weather mission designed for civilian use. Landsat proved the feasibility of observing Earth from space. Its success encouraged the private sector to launch their own Earth-observing instruments, with companies such as DigitalGlobe and entities such as the National Geospatial-Intelligence Agency now maintaining privately owned satellites.



James Irons

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Technology Transfer

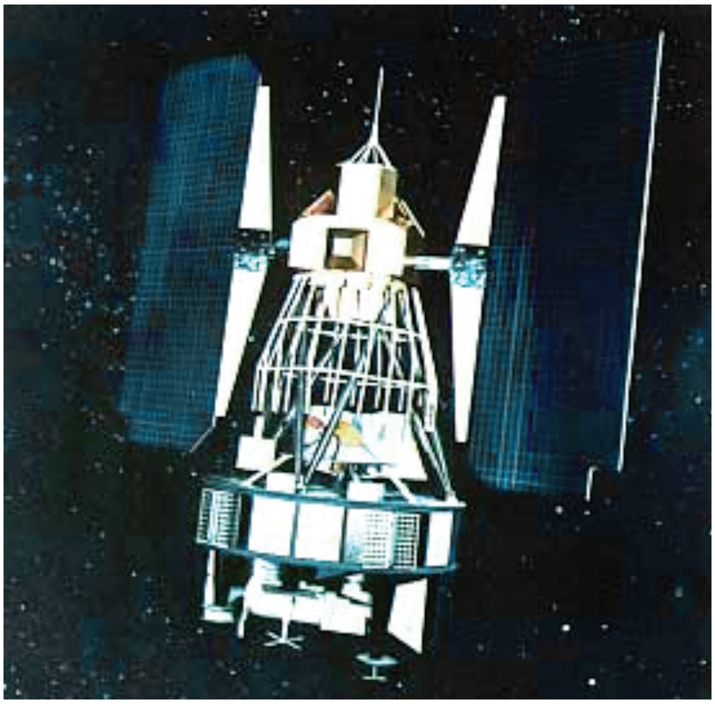
As we explain in a separate article, Landsat data is currently being used in a wide variety of ongoing applications. In addition, technologies originally developed and/or adapted for Landsat missions have also been adapted to uses outside the program. In this article, we look at a few examples of how Landsat and its associated hardware have been leveraged for commercial markets.

For more information about the Landsat Data Continuity Mission/Landsat 8, see the article "Landsat Data Continuity Mission Overview" in this issue of the NASA Goddard *Tech Transfer News.*

Landsat: Establishing a new industry

When considering the Landsat program's overall impact on the private sector, it's important to note that the program itself helped launch a new commercial industry, one that thrives to this day. According to LDCM Project Scientist Dr. James Irons, Landsat 1 was the first non-weather civilian satellite dedicated to monitoring phenomena on the land surface of the Earth. Previous Earth-observing satellites were either designed to monitor weather, or were intended for military purposes. Landsat 1 and its early successors demonstrated that observing Earth from a space-based platform over an extended period of time was technically possible. This in turn encouraged other entities, including private companies, to develop and launch their own Earth observation instruments.

Today applications and products associated with Earth observation from space comprise a multi-billion dollar global opportunity. According to an industry report (see http://eomag.eu/articles/604/satellite-based-earth-observation-entering-expansion-phase-with-record-high-of-nearly-200-satellites-expected-to-be-launched-by-2017-nascent-private-sector-and-emerging-government-programs-fuelling-growth) analysts expect that nearly 200 Earth-observing satellites will be launched between the years 2007 through 2017, with private industry representing one of the fastest-growing segments of this market. Major players include the U.S.-based DigitalGlobe and the Dutch company ImageSat.



▶ *Landsat 1 in orbit (artist's conception).*

—IMAGE BY NASA

Following the path pioneered by Landsat, commercial satellite companies have incorporated new technologies that provide increased capabilities while reducing size, weight, and cost. This allows these companies to provide data products to users in a number of different markets. In addition, popular Internet-based programs such as Google Earth and Microsoft Virtual Earth allow the general public to access and use spaced-based Earth imagery, raising awareness of this data and potentially driving further demand for similar services.

“Whisk broom” scanning: an early Landsat innovation

From the beginning, the Landsat program has contributed spinoff technologies that have found terrestrial uses. One example is a digital imaging technique known as “whisk broom” scanning (a.k.a. electo-mechanical scanning). According to Dr. Irons, during the Landsat 1 mission a whisk broom scanner called the Multispectral Scanner System (MSS) proved superior to a video technology instrument called the Return-Beam Vidicon (RBV) system.

Engineers at Hughes Aircraft Company developed the MSS under contract to NASA as an experimental technology for the Landsat 1 payload. The MSS captured digital images via an oscillating mirror that sweeps the field of view. This allows the instrument to collect data in a continuous swath along the satellite ground path. Due to the demonstrated performance of the MSS on Landsat 1, whisk broom scanning was employed successfully on all subsequent Landsat missions through Landsat 7, establishing this technology as viable and reliable. Whisk broom scanning has also been applied to many other remote sensing satellite missions.

Shipping container for TIRS

—PHOTO BY NASA

Quantum Well Infrared Photodetector (QWIP)

A relatively recent technology developed to support the ongoing Landsat program is the “Quantum Well Infrared Photodetector (QWIP) Focal Plane Assembly” (GSC-15849-1) developed for the LDCM/Landsat 8 Thermal Infrared Sensor (TIRS) instrument.

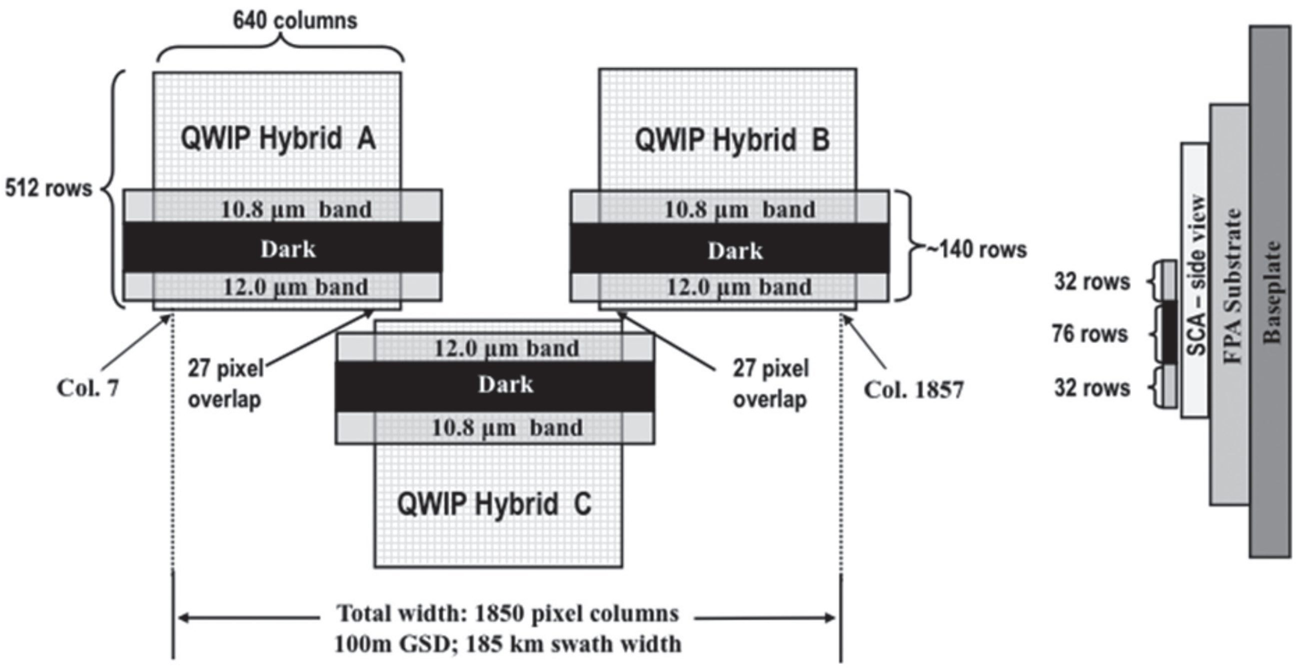
According to Dr. Irons and Dr. Murzy Jhabvala (Chief Engineer, Instrument Systems and Technology Division, Code 550), QWIP was a late addition to the LDCM effort. The original TIRS instrument concept considered for LDCM was based on microbolometer technology. However, during the development of LDCM it was discovered that this technology could not meet the mission’s demanding requirements, calling into question whether or not the TIRS instrument would be included on Landsat 8.

The LDCM team then approached Dr. Jhabvala to determine whether or not his ongoing work with QWIP technology could be leveraged to replace the microbolometer instrument design. Despite the accelerated schedule, Dr. Jhabvala, in collaboration with others, developed a QWIP-based instrument in time to be included onboard Landsat 8, where it is now operating flawlessly. (See also “Interview with Dr. James Irons and Dr. Murzy Jhabvala” in this issue of the NASA Goddard *Tech Transfer News*.)

The resulting TIRS instrument incorporates three large format infrared detecting arrays based on QWIP technology onto a common focal plane, providing precision alignment of all three arrays. It’s important to note that this focal plane must survive the harsh demands of flight qualification while operating at a temperature of 43 Kelvin for five years on Earth orbit. To meet these demands, Dr. Jhabvala and his colleagues developed a custom silicon substrate to serve as the carrier board for the TIRS instrument’s three QWIP arrays.

According to Dr. Jhabvala, QWIP technology has been around since the early 1980s, and has seen very significant advancement in recent years. QWIP will allow Landsat 8 to provide critical data for global water resource management. Other applications under consideration for QWIP-based instruments include military (such as landmine detection) and environmental monitoring (for example oil spills). QWIP is also being considered for non-space applications such as medical diagnostics.

Although GSC-15849-1 has been developed specifically for LDCM, the general concept of building larger focal planes on a single silicon substrate may have application to other focal plane based applications. In addition, NASA Goddard’s partner QmagiQ has leveraged QWIP technology to deliver commercial systems designed for sensor engines and camera systems. For more information about QWIP, its role in LDCM, and its potential applications; consult the paper “Quantum Well Infrared Photodetector Innovation Pathway” (http://www.seas.gwu.edu/~zszajnfa/docs/QWIP%20pathway.pdf) on George Washington University’s web site.



The TIRS focal plane design showing the position of the three QWIP hybrids and the filter bands (left) and a cross sectional view of the focal plane construction (right)

—IMAGE BY NASA

Other LDCM-related technologies

In addition to GSC-15849-1, two other New Technology Reports (NTRs) have been reported for technologies associated with the LDCM development effort:

Focal plane front-end electronics for TIRS (GSC-16057-1) is based on Teledyne's SIDECAR Application Specific Integrated Circuit (ASIC) chip. The focal plane electronics (FPE) for TIRS must command and control the TIRS focal plane assembly (FPA), extract analog signals from the FPA, convert the analog signals to digital format, and then send this data to a computer via a USB serial link. To do this, the FPE converts electrical power from generic power supplies to the bias power needed by the FPA. The FPE also generates digital clocking signals and shifts the typical transistor-to-transistor logic (TTL) to +/- 5 volts required by the FPA.

As noted above, TIRS incorporates three QWIP detector arrays; all three detector arrays must be in synchronization during operation to avoid data skewing while observing Earth from space. This technology allows researchers to customize the observing scenario by uploading new control software to the SIDECAR. As a result, the FPE is extremely flexible. Although the TIRS FPE is designed specifically for the requirements of LDCM; a commercial company has expressed interest in using it for a global survey application under a Space Act Agreement.

TIRS Single Crystal SiliconScene Select Mirror (GSC-16515-1) is a robust mirror for mounting where flexures may not be fully optimized. Vibration testing has determined that this mirror provides superior mechanical performance to an aluminum substrate mirror, with no need for notching. In addition, cold figure testing of the mounted mirror indicated that all LDCM optical requirements are met, including cold figure and repeatability. This mirror has been qualified for space flight use to the TIRS environmental qualification requirements.

Conclusion

It probably goes without saying that during the past four decades Landsat data has provided incalculable benefit to society, throughout the globe, in many different applications. Lesser known may be the fact that technologies developed for LDCM and its predecessors in the Landsat program have also provided value to users back here on Earth, often in ways the original inventors may not have anticipated. This article briefly reviews a few examples of these technologies, further demonstrating the high return on investment the Landsat program continues to provide to many millions of people throughout the world.

SBIR/STTR Success Story

Recent Landsat missions have tended to incorporate technologies that have already achieved a high Technology Readiness Level (TRL). As a result, these missions have generally not relied heavily on developing new technologies through venues such as the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs. However, LDCM/Landsat 8 did take advantage of SBIR funding to help develop two technologies critical for Landsat's ongoing success. These include QWIP technology on which Landsat 8's Thermal Infrared Sensor (TIRS) instrument is based. It also includes the airborne system and data reduction technology used by TIRS.

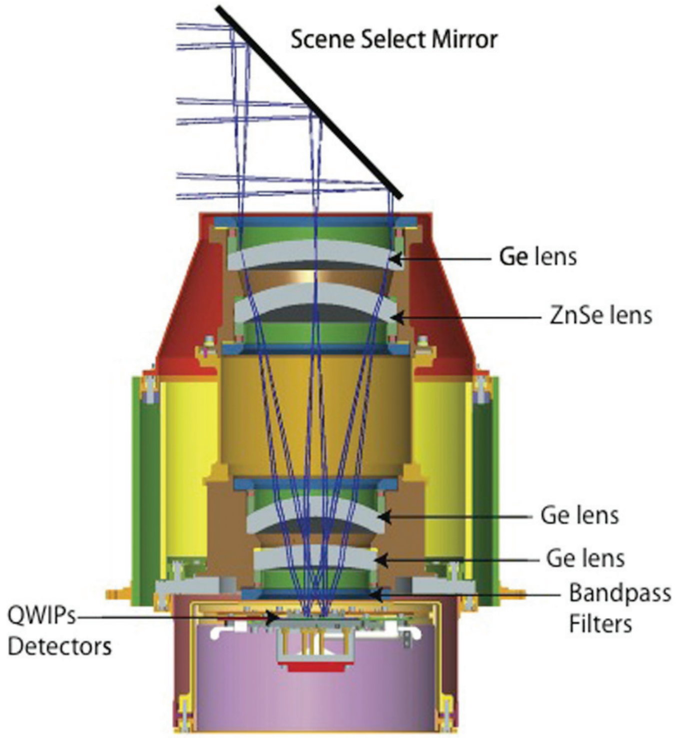
QmagiQ and QWIP

As explained elsewhere in this issue of NASA Goddard *Tech Transfer News*, the original design for the LDCM infrared detector was based on microbolometer technology. However, after several years of development this design proved unsatisfactory; so the LDCM team turned to a relatively novel technology known as quantum well infrared photodetectors (QWIP). And to accommodate the accelerated schedule, NASA Goddard partnered with QMagiQ to help develop a QWIP design suitable for the LDCM mission.

QmagiQ originally worked with NASA Goddard via an SBIR grant to develop a QWIP–based infrared camera. This technology was eventually leveraged into a commercially available compact portable infrared camera with interchangeable quantum well Infrared photodetectors sensor cartridges. This camera has been used at NASA Goddard for field investigations such as locating caves in a desert landscape from an aerial platform. Other potential applications for this camera include chemical/spectral mapping of forests, vegetation, crops, and landmasses; pollution monitoring; temperature mapping; and atmospheric sensing. *(See also the Spring 2012 issue of the NASA Goddard* Tech Transfer News*. Http://ipp.gsfc.nasa.gov/newsletter/TechTransferNews-Spring12.pdf)*

The success of the QmagiQ camera helped convince the LDCM team that QWIP could address their requirements for an infrared imaging system. So NASA Goddard

QmagiQ's QWIP-based infrared camera.
—PHOTO BY NASA



▶ *Diagram of TIRS showing placement of QWIPs.*

—PHOTO BY NASA

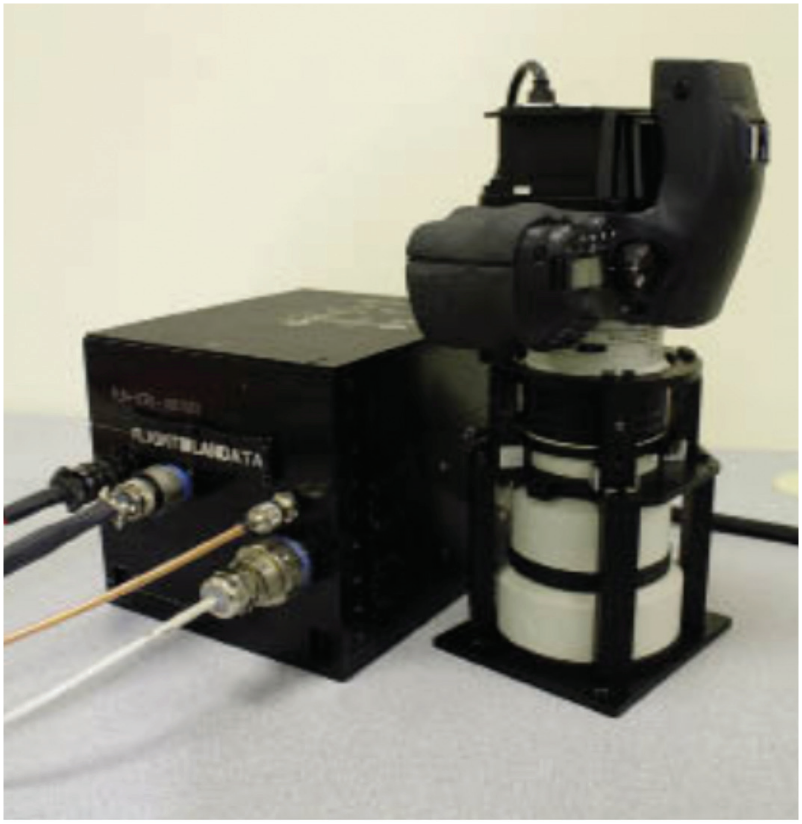
again partnered with QmagiQ under a Space Act Agreement to help develop QWIP arrays for the TIRS instrument. These arrays are now an integral part of the TIRS instrument on Landsat 8.

Flight Landata and spectral imaging

Another component of the TIRS instrument is the lightweight spectral imager, developed in partnership with Flight Landata Inc. (*see http://ipp.gsfc.nasa.gov/newsletter/TechTransferNews-Winter11.pdf*), of North Andover, Massachusetts working through several SBIR grants. Throughout the Landsat program, SBIRs have provided funding for the development of several critical imaging technologies, including a smaller computer processor for the imaging system, increased sensitivity in the detector system, and a stabilized gimbal system to maintain the unit's image fidelity despite movement of the aircraft. Flight Landata has received the 2002 Tibbetts Award from the U.S. Small Business Administration, as well as the U.S. Army's Greatest Invention of the Year award for 2006.

Flight Landata's BuckEye remote imaging system builds upon these SBIR-funded technologies. BuckEye is designed to capture extremely high spatial resolution images in three spectral bands. This imagery data is then combined with LIDAR technology to produce three-dimensional images and digital elevation models.

BuckEye technology has been incorporated into LDCM/Landsat 8. Its data reduction technology will provide multispectral images that parallel the ones that will be produced by the sensors onboard Landsat's TIRS instrument. This data is then used to help calibrate LDCM instruments.



▶ *Flight Landata's BuckEye system.*

—PHOTO BY NASA

[THE IMPACT TO DATE *of the America Invents Act*

Regular readers of Patenting Perspectives will recall that we've discussed various aspects related to the Leahy-Smith America Invents Act (AIA) a number of times in previous issues of the NASA Goddard *Tech Transfer News*. Signed into law on September 16, 2011, AIA represents what is widely considered the most significant change to the U.S. patent system in over 60 years. Among its more important modifications are provisions that move U.S. patent law (historically a "first-to-invent" patent system) closer to the worldwide norm of "first-to-file." Several major components of AIA took effect on March 16, 2013.

In this Patenting Perspectives article, attorneys Bryan Geurts (Chief Patent Counsel for NASA Goddard's Office of Patent Counsel) and Erika Arner (Partner for the law firm Finnegan, Henderson, Farabow, Garrett & Dunner) discuss how AIA has altered the U.S. patenting landscape to date, which area causes the most confusion among inventors, and related topics.

Q. *What's the current status of the deployment of AIA? Has it resulted in any unexpected problems?*

▶ *Bryan Geurts*

Bryan: As of March 16, 2013, all of the substantive provisions have been deployed. Only a few provisions, such as those requiring the opening of USPTO satellite offices, remain to be implemented. To date, nothing has really gone wrong, although it is still very early in the game; I expect that it will take some time before any real negative fallout from AIA becomes obvious.

▶ *Erika Arner*

Erika: We're still at an early stage in the implementation of AIA. So far there have been two challenges filed against the U.S. Patent Office involving the AIA post-grant review provision. These challenges claim that the USPTO has exceeded the authority granted to it by AIA. Both challenges have been dismissed in court; they are currently being appealed, so it will be some time before we know whether either challenge is ultimately successful.

Bryan: Considering how major a change AIA represents, there have been remarkably few challenges to date, fewer than I expected. I'm a little surprised.

Erika: I agree, although I'd also add the caveat that the most recent changes haven't yet been fully implemented. I suspect that the "first-to-file" provision will eventually provoke more challenges.

Q. *What component of AIA appears to be working especially well or better than expected?*

Erika: The Track One prioritized examination procedure, in which the USPTO "fast tracks" a patent application for a special fee, has been very well received. Of all AIA provisions, this may be the most pleasant surprise in terms of how well it has worked.

Bryan: Track One filing is definitely a good thing. We have already taken advantage of it here at NASA Goddard for high-priority inventions.

Q. ***Has the implementation of AIA necessitated re-training for inventors?***

Bryan: We've been doing a lot of training to get the message across. This includes sending out circulars explaining AIA and our new requirements for it. We've also taken a person-to-person approach, going to NASA Goddard's Science and Engineering branches and meeting with inventors one-on-one.

Erika: Virtually every recent legal or scientific conference includes training sessions on AIA. Many companies provide their own in-house training, as do legal firms. My own firm, Finnegan, Henderson, Farabow, Garrett & Dunner, offers a detailed blog specifically dedicated to AIA and its ramifications (*see http://www.aiablog.com*). There are also books being written about AIA.

Q. ***Are there any specific areas about which inventors frequently have questions?***

Bryan: First-to-file seems to produce the greatest level of misunderstanding since it puts more pressure on inventors to make the "patent or disclose" decision earlier. And if they do decide to disclose, it's important to disclose everything and put it out on a public web site to prevent someone else from claiming priority to the invention and using it against us someday.

Erika: When we do training, first-to-file causes the most confusion because it re-defines what comprises prior art, a concept that's been in place for generations. First-to-file re-writes the law concerning prior art. The intent is to harmonize the definition with the rest of the world's; but in the process AIA also significantly broadens the definition. We don't yet have case law to help develop the definition; this is an important point with high stakes.

Bryan: The new definition of prior art is probably the biggest "gotcha" associated with AIA, with many significant parties interested in this topic. I suspect that this could eventually result in significant legal challenges.

Bryan Geurts

CHIEF PATENT COUNSEL

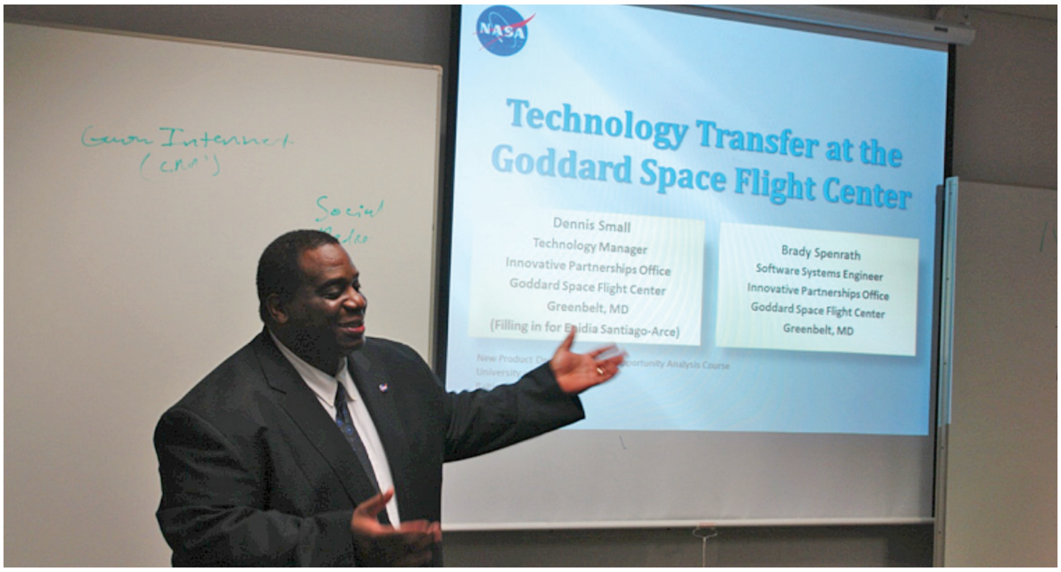
Code: 140.1

Years with NASA: 11

Education:
B.S.Civil Engineering, B.A. German from University of Utah

Juris Doctor Degree from Brigham Young University

Networking and Outreach



▸ *ITPO Technology Manager Dennis Small talks with University of Baltimore students about NASA Goddard's technology transfer efforts.*

—PHOTO BY NASA

ITPO Visits University of Baltimore

(APRIL 30, 2013, BALTIMORE, MD)

Innovative Technology Partnerships Office (ITPO) Technology Manager Dennis Small and Commercialization Specialist Brady Spenrath visited the University of Baltimore (U of B) on February 5, 2013, to explain the fundamentals of government technology transfer to Dr. Michael Laric's marketing class. Through a partnership between NASA Goddard and the University of Baltimore, the ITPO offers U of B students a choice from several promising technologies, and the students (working under a NASA Non-disclosure Agreement) work in teams to conceive new applications for the technologies, and draft business plans based on how they would use the technology. The students learn valuable lessons about marketing, business model development, and venture capital, while the ITPO utilizes their application and marketing ideas when seeking partners and licensees for the technologies. Small and Spenrath returned to U of B on April 30, 2013, to listen to the students' impressive final presentations.

Open Source Summit

(JUNE 25-26, 2013, WASHINGTON, DC)

Open Source Summit v3.0: Commu

Over June 25-26, 2013, Technology Manager Enidia Santiago-Arce and Commercialization Specialists Andrei Zorilescu and Brady Spenrath participated in the third annual Open Source Summit, held at NYU Washington, D.C. This knowledge-sharing and networking event allowed corporations, small businesses, entrepreneurs, and government agencies to learn from seasoned experts, and openly discuss best practices regarding building effective open source communities, and improving software or processing data through crowdsourcing.

Society of Manufacturing Engineers

(JUNE 2-4, 2013, BALTIMORE, MD)

NASA Goddard's Innovative Technology Partnerships Office (ITPO) participated in the Society of Manufacturing Engineers (SME) Annual Conference held in Baltimore, MD, on June 2 – 4, 2013. This annual event offers attendees a chance to meet and talk with local businesses that are driving innovation in the manufacturing field and advancing the manufacturing workforce. ITPO staff members were on hand to speak with attendees on licensing and partnership opportunities, and provided information on partnering with NASA Goddard. SME members were also given a tour of Goddard facilities and labs and were treated to talks from Goddard's Center Chief Technologist Peter Hughes and ITPO Senior Technology Manager, Darryl Mitchell.

Innovative Technology Partnerships Office staff members Brady Spenrath and Andrei Zorilescu talk with attendees at the 2013 Society of Manufacturing Engineers Annual Conference in Baltimore, Maryland.

—PHOTO BY NASA

Author and Innovation Expert Jim Carroll, speaks at the ITPO Innovative Initiatives meeting and demonstrates an interactive poll with audience members.

—PHOTO BY NASA

Goddard Innovator Initiatives Speaker Series with Author Jim Carroll

(GREENBELT, MD, JUNE 10, 2013)

The Innovative Technology Partnerships Office (ITPO) hosted author and innovation expert Jim Carroll at Goddard on June 10, 2013. The audience included Goddard management, innovators, and program/project managers. Carroll addressed increasing work output, despite possibly diminishing resources, through formation of strategic collaborations. After Carroll's presentation, he facilitated a discussion regarding connecting with high quality collaborative partners through a fast and targeted approach without compromising agency or center policies, intellectual property assets, or strategic plans. A separate round table discussion highlighted ways to enhance how information is exchanged to better capitalize on existing relationships, and attract wider scientific partners, technical partners, and projects.

▶ *The South African Ministry of Science visited Goddard to meet and talk with GSFC Management.*

—PHOTO BY NASA

Technology Innovation and Technology Transfer Training

(JUNE 6, 2013, GREENBELT, MD)

Innovative Technology Partnerships Office (ITPO) staff member Joseph Holmes, conducted a training course for Goddard scientists and engineers on how to properly disclose their inventions, and what happens to their technology after the ITPO receives their New Technology Report. On Tuesday, June 6, 2013, Holmes led the two-hour training session instructing contractors and civil servants, both new and experienced. Topics included what constitutes an invention, at what point in the development cycle to report a technology, the ITPO's process of marketing and commercialization, and the awards and royalties inventors can earn for reporting. The course also touched on Intellectual Property (IP) management.

South African Dignitaries Visit Goddard

(JUNE 21, 2013, GREENBELT, MD)

The South African Ministry of Science and additional dignitaries visited Goddard on June 21, 2013 to speak with management, engineers, and scientists regarding Goddard's Space Directorate. A tour of the Goddard facilities included visits to the VisWall, James Webb Space Telescope, Magnetospheric Multiscale Mission, and Global Precipitation Measurement facilities. Opportunities for a partnership with South Africa and its developing space program are forming.

Landsat 8

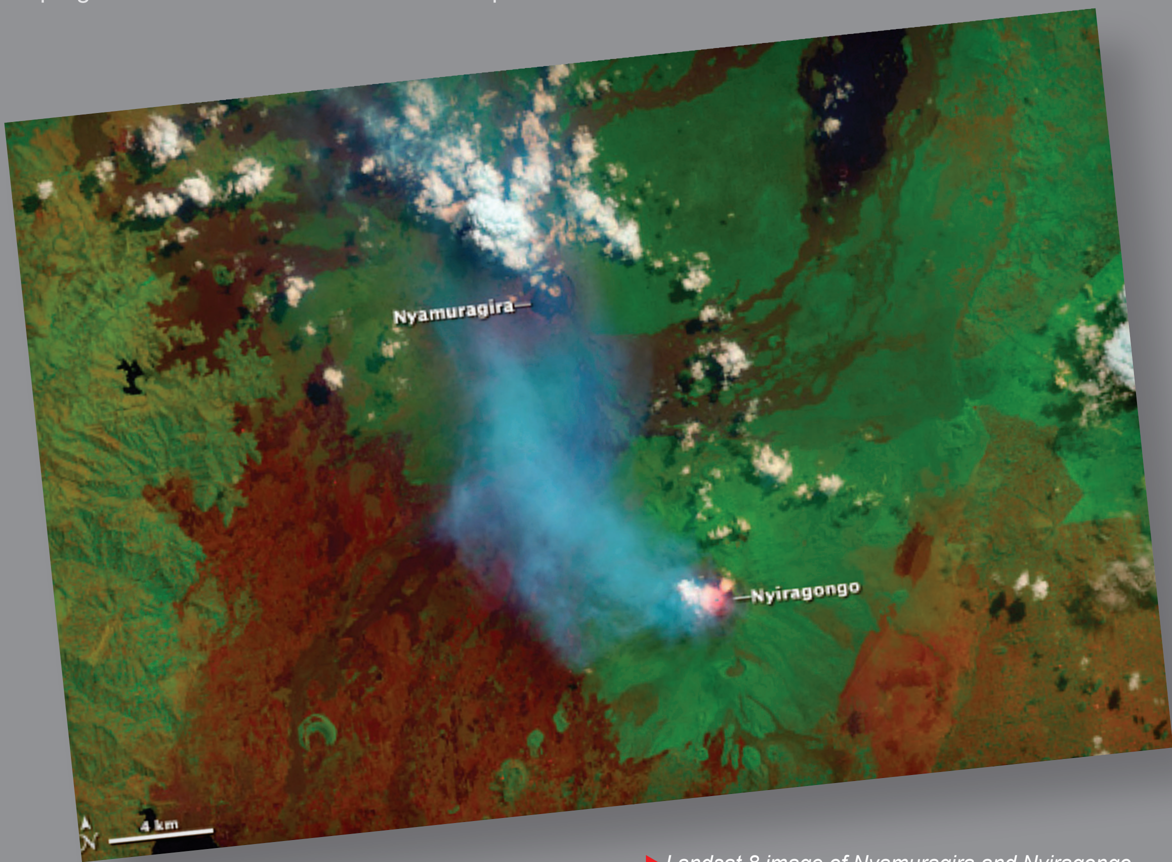
In the News

The following is a brief review of a few recent news stories prominently featuring NASA Goddard and the Landsat Data Continuity Mission/Landsat 8.

New NRC Report Calls for Sustained Landsat Program

On August 8, 2013, the U.S. National Research Council (NRC) issued a report titled "Landsat and Beyond: Sustaining and Enhancing the Nation's Land Imaging Program." In this report, the NRC calls for a "systematic and deliberate program" to ensure that there is no disruption of service in Landsat's mission to compile an ongoing and uninterrupted record of moderate-resolution imagery of the Earth's land surface. The report further recommends that the U.S. government establish a comprehensive national strategy and long-term commitment for a sustained and enhanced land imaging program. This program needs to include clearly defined requirements, management responsibilities, and stable funding.

For more information, see http://www.spacenews.com/article/civil-space/36717new-nrc-report-calls-for-sustained-landsat-program.



▶ *Landsat 8 image of Nyamuragira and Nyiragongo.*

—PHOTO BY NASA

Landsat 8 Images Congo Volcanoes

On July 29, 2013, Landsat 8 imaged the volcanoes Nyamuragira and Nyiragongo. These mountains are located within the Democratic Republic of the Congo, and are considered to be among the most active on Earth.

Nyiragongo features a persistent lava lake, which in the preceding image appears as a red glow of shortwave infrared light. Note also the dense, white plume drifting from Nyamuragira. The color indicates that this plume includes a large amount of water vapor. In the surrounding landscape, forest appears as bright green, cleared areas as red-brown, and old lava flows various shades of black, brown, and green.

For more information, see http://www.satnews.com/story.php?number=409835195.

Earthshots Web Site Allows Users Access to Landsat Data

The U.S. Geological Survey's Earthshots web site (http://earthshots.usgs.gov/earthshots/) provides the public with access to Landsat imagery data. Earthshots allows users to explore how the surface of our planet has transformed over the 41 years the Landsat program has been in operation.

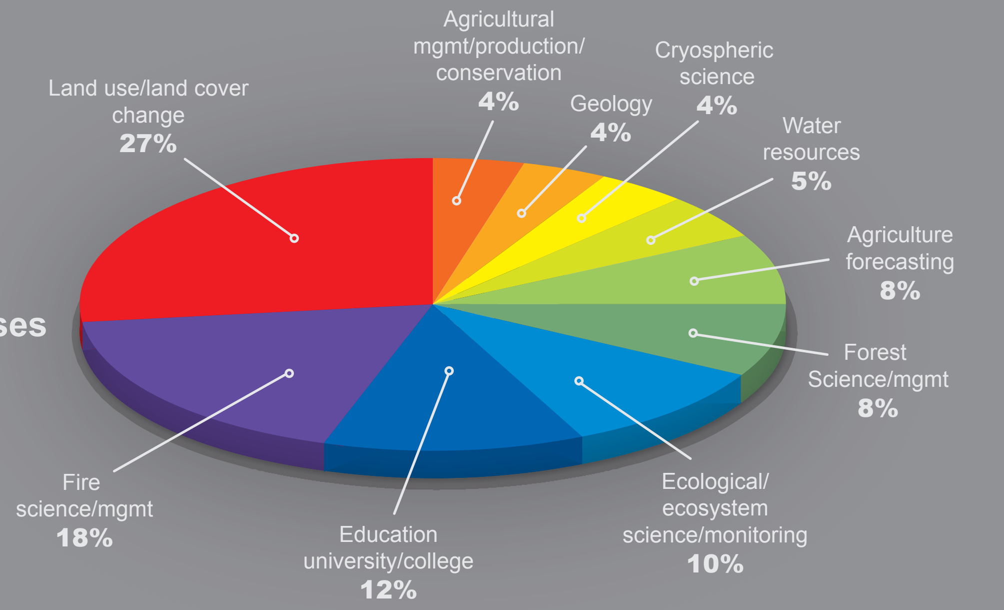
Data from Landsat has been used in a broad variety of important applications. For instance, Landsat data:

- Helps rescue workers target their efforts by supplying images of towns before and after natural disasters
- Allows for better forest management and deforestation tracking
- Provides remote sensing tools that aid in fire science such as wildfire control planning
- Assists agricultural planners to understand water resources, forecast crop success, and plot how invasive species damage local plants
- Helps city planners to map how urban areas enlarge and change

Landsat satellites obtain data from regions that would otherwise be very difficult to observe through other means. These instruments also capture information in spectrum bands that are beyond the capability of human eyes, such as infrared wavelengths. The two currently-operating Landsat spacecraft (Landsat 7 and Landsat 8) each orbits the Earth once every 99 minutes; together they provide images once every eight days of any region on Earth.

For more information, see http://community.adn.com/node/163626.

Primary Data Uses



Landsat 8

[DISCLOSURES AND *Patents*

Technology Disclosures

Disclosures

- **DIGITALLY STEERED PHASED ANTENNA ARRAY FOR GPS APPLICATIONS**

  Luke Winternitz, Heitor Pinto, Jennifer Valdez, Samuel Price, Lawrence Han, Monther Hasouneh

- **MINIATURIZED RADIATION HARDENED BEAM-STEERABLE GPS RECEIVER**

  Michael Shaw

- **ADVANCED TOOL DRIVE SYSTEM (ATDS) - TOOL DRIVE END EFFECTOR (TDEE) A COMBINED ROBOTIC TOOL CHANGE-OUT MECHANISM AND TOOL DRIVE INSTALLED AT THE END OF ROBOT ARM; COUPLER - A 3-JAW LATCH SYSTEM THAT GRASPS A MATING INTERFACE PLATE ON EACH TOOL; DRIVE ACTUATORS CAN TRANSFER TORQUE TO MATING SPLINES OF A TOOL, TO PROVIDE ROTARY OR LINEAR MOTION**

  Paul Nikulla, Alejandro Rivera, Edward Cheung, Thomas McBirney, Mark Behnke, Michael Liszka

- **PRECIPITATION IMAGING PACKAGE (PIP)**

  Francis Bliven

- **MAGNETIZING DRY LUBRICANTS AND BEARING SURFACES FOR EASY CAPTURE WITH A MAGNETIC TRAP**

  S. Harvey Moseley

- **CLOSED-FORM (ANALYTICAL) SEW-ANGLE INVERSE KINEMATIC SOLUTION FOR THE 7-DOF FREND ROBOTIC ARM**

  Will Clement, Hui An

- **BUG FIXES AND UPGRADES TO OU/NOAA'S EF5 ENSEMBLE MODELING FRAMEWORK, AND THE COUPLED ROUTING AND EXCESS STORAGE (CREST)**

  John David, Zac Flamig

- **A REDUCED-COST CHIRPED PULSE FOURIER TRANSFORM MICROWAVE SPECTROMETER USING DIRECT DIGITAL SYNTHESIS**

  Ian Finneran, Daniel Holland, P. Carrol, Geoffrey Blake

- **OPTICALLY MODULATED MINIATURE MAGNETOMETER (OMMM)**

  Andy Brown, Robert Slocum

- **MULTI-MISSION PLANNING TOOL (MMPT) FOR EARTH SCIENCES FLIGHT OPERATIONS (TERRA, AQUA, AURA)**

  Jon Touchstone, Pete Johansen, David Bykowski, Jody Caldwell

- **MINIATURE RELEASE MECHANISM OR DIMINUTIVE ASSEMBLY FOR NANOSATELLITE DEPLOYABLES (DANY)**

  Luis Santos, Scott Hesh, John Hudeck

- **EXTRAVEHICULAR ROBOTIC (EVR) NOZZLE TOOL (ENT)**

  Matthew Ashmore

- **PROPELLANT TRANSFER ASSEMBLY DESIGN AND DEVELOPMENT**

  Phillip Kalmanson, Brian Nufer, Stephen Anthony, Craig Fortier

- **RELEASE OF A STUCK SOLAR ARRAY OR ANTENNA - CONCEPTS**

  Paul Nikulia, Michael Liszka, Alejandro Rivera, Edward Cheung, Thomas McBirney, Mark Behnke

- **GEO-REGISTRATION OF MULTI-SOURCE IMAGE DATA FOR SENSORWEB APPLICATIONS**

  Jacqueline Le Moigne-Stewart, Daniel Mandl, Vuong Ly, Patricia Sazama

- **CHEMICAL SENSORS BASED ON 2-DIMENSIONAL MATERIALS**

Mahmooda Sultana

- **DAMAGE-FREE FINISHING OF SILICON X-RAY OPTICS USING MAGNETIC FIELD-ASSISTED FINISHING**

Hitomi Greenslet, Raul Riveros

- **THREE SOFTWARE PLUGINS FOR THE NASA GMAT (GENERAL MISSION ANALYSIS TOOL) MISSION DESIGN SOFTWARE: 1. AUTO CONTINUATION PLUGIN FOR PLOTTING FAMILIES OF PERIODIC ORBITS. 2. DMOC PLUGIN FOR OPTIMAL CONTROL SUBJECT TO CONSTRAINTS. 3. ARENA PLUGIN FOR STATE ESTIMATION.**

Randy Paffenroth, Kyle Tarplee, Woody Leed, Philip Du Toit

- **META-MATERIAL BLOCKING FILTER WITH LOW GEOMETRIC INDUCTANCE**

Kongpop U-yen, Samuel Moseley, Edward Wollack

- **TWO-CHANNEL 3 GSAMP/SECOND ADC AND FPGA BOARD FOR DIGITAL DOWNSAMPLING HIGH-BANDWIDTH AND HIGH DATA-RATE MICROWAVE (L-BAND) INTERFEROMETRIC OR POLARIMETRIC SIGNALS**

Paul Siqueira, Russell Tessier, Vishwas Vijayendra

- **SPACE WEATHER SCOREBOARD**

Chiu Wiegand, Richard Mullinix, Marlo Maddox

- **NEGATIVE ION TIME PROJECTION CHAMBER POLARIMETER FOR MEASURING THE POLARISATION OF BRIGHT TRANSIENT ASTROPHYSICAL SOURCES**

Joel Black, Joanne Hill, Philip Kaaret

- **CLOSED-FORM (ANALYTICAL) SEW-ANGLE INVERSE KINEMATIC SOLUTION FOR THE 7-DOF MOTOMAN SIA-50D ROBOTIC ARM**

William Clement, Hui An

- **SPACECUBE COMMUNICATION INTERFACE BOX**

Daniel Espinosa, David Petrick, Thomas Flatley, Jeffrey Hosler, Robin Ripley, Manuel Buenfil, Pietro Sparacino, Sanetra Bailey, David Hardison

- **GODDARD NATURAL FEATURE IMAGE RECOGNITION (GNFIR) ALGORITHM (SOFTWARE AND FIRMWARE)**

John Van Eepoel, Steve Queen, Nathaniel Gill, Alessandro Geist

- **INFRARED MICROSPECTROMETER BASED ON MEOMS LAMELLAR GRATING INTERFEROMETER**

Michael Morley, Silviu Velicu

- **FLEXIBLE HARNESS CIRCUIT DESIGN FOR CANCELLATION OF RECEIVED NOISE ONTO DATA SIGNAL LINES**

Edward Cheung

- **MINIATURE LASER MAGNETOMETER (MLM)**

Andy Brown, Robert Slocum

- **VISUALIZATION OF TERASCALE DATASETS WITH IMPOSTORS**

Thomas Quinn

- **DEVELOPMENT OF TECHNOLOGY FOR A COMET SAMPLE RETURN MISSION - VERSION 2**

Joseph Nuth, Donald Wegel, Lloyd Purves, Edward Amatucci, Michael Amato

- **THE DEVELOPMENT OF A NEW CRYOGENIC OPERATED SOLENOID**

Rajeev Sharma

- **A PROCESS FOR MITIGATING PARTICULATE CONTAMINATION FROM BEARING SURFACES**

Samuel Moseley

- **ADVANCED TOOL DRIVE SYSTEM (ATDS) - CAMERA POSITIONING MECHANISM (CPM) THE COMBINATION OF A CAMERA, LENS AND ELECTRO-MECHANICAL EXTENSION DEVICE; INSTALLED ON THE END OF A ROBOTIC ARM, BUT EQUALLY COULD BE INSTALLED AT ANY LOCATION NEEDED TO PROVIDE FOCUSED VIEWS OF A ROBOTIC WORKSITE. THE CPM HOUSES A CAMERA, LENS AND MECHANISMS WHICH EXTEND AND PITCH THE CAMERA LENS IN ORDER TO PROVIDE ROBOTIC TELE-OPERATORS WITH A VISUAL IMAGE OF WORKSITE ACTIVITIES AT THE TIP OF A TOOL ATTACHED TO THE ATDS, WHICH IS ATTACHED TO THE END OF A ROBOT ARM, OR OTHER FEATURES ON A CLIENT SATELLITE**

Edward Cheung, Jonathan Kraeuter

- **ARC: ACCELERATED RELOCATION CIRCUIT FOR XILINX FPGAS**

Aravind Dasu, Ramachandra Kallam

- **THERMAL-CONTRACTION MATCHED HYBRID FPA DESIGN FOR ALUMINA PACKAGES**

Donald Cooper, Lisa Fischer

- **TRANSITION REGION AND CORONAL EXPLORER (TRACE) LIMIT CHECKER (LC) APPLICATION**

Michael Blau, Larry Shackleford

- **PARTICULATE FILTER BASED ON GRAPHENE AND GRAPHENE DERIVATIVES FOR CLEAN AIR APPLICATIONS**

  Mahmooda Sultana

- **2.2 MICRON, UNCOOLED, INGAAS PHOTODIODES AND BALANCED PHOTORECEIVERS UP TO 25 GHZ BANDWIDTH**

  Abhay Joshi

- **TOOL STOWAGE CANTILEVER LAUNCH LOCK**

  Richard Michael, William Squicciarini

- **ADVANCED TOOL DRIVE SYSTEM (ATDS) - BLDC MOTORS BRUSHLESS DC ELECTRIC MOTORS USED INSIDE THE ATDS TO PROVIDE TORQUE TO THE FOUR ACTUATORS - COUPLER DRIVE, LINEAR DRIVE, INNER ROTARY DRIVE AND OUTER ROTARY DRIVE. DRIVE ACTUATORS CAN TRANSFER TORQUE TO MATING SPLINES OF A TOOL, ATTACHED TO THE ATDS, TO PROVIDE ROTARY OR LINEAR MOTION**

  Paul Nikulia, Michael Liszka, Alejandro Rivera, Edward Cheung, Thomas McBirney, Matthew Ashmore, Mark Behnke

- **INTEGRATED COMPOSITE — HEATPIPE RADIATOR PANEL**

  Mark Montesano

- **COMPACT APPARATUS FOR MEASURING THE SEEBECK COEFFICIENT OF THIN METALLIC FILMS**

  Emily Barrentine, Ari Brown

- **VIDEO DISTRIBUTION & STORAGE UNIT (VDSU) SSCO RESTORE PROGRAM**

  Madhu Kadari, Serge Svovsky, Seshagiri Nadendla

- **SPACE WEATHER DATABASE OF NOTIFICATIONS, KNOWLEDGE, INFORMATION (DONKI)**

  Richard Mullinix, Chiu Wiegand, Mario Maddox

- **INTELLIGENT PAYLOAD MODULE**

  Daniel Mandi, Vuong Ly, Matthew Handy

- **DEVELOPMENT OF A DIFFUSE COATING WITH HIGH ABSORPTANCE FOR MULTILAYER INSULATION COVER TO MINIMIZE SUNLIGHT GLINT TO CAMERAS IN FLIGHT**

  Michael Choi, Kenneth O'Connor, Mark Hasegawa

- **RADIATION HARDENED 10BASE-T ETHERNET PHY**

  Michael Lin, Kevin Ballou, Daniel Espinosa, Edward James, Matthew Kliesner, David Petrick

- **MAVEN FLIGHT AND GROUND SOFTWARE**

  Lawrence Ellis, Angela Boggs, Gregory Bollendonk, Kristina Bogar, Sibel Clark, Martin Coltrin, Jason Dates, William Fehringer, Paul Fleming, Jeffrey Harris, Janet Hatstat, Geoffrey Hauser, David Hirsch, Mary Klaus, Karl Langas, Edward Lichtenfels, Matthew McIllese, Trevor Merkley, Lorn Miller, Doug Niebur, Yegor Plam, Randy Pletzer, Monte Ratajczyk, Paul Roberts, Mark Scott, Jay St. Pierre, Michael Stevens

- **NON-LINEAR NON-STATIONARY ANALYSIS OF 2D TIME SERIES APPLIED TO GRACE DATA**

  Scott Luthcke, Nicolas Gagarin

Patents Issued

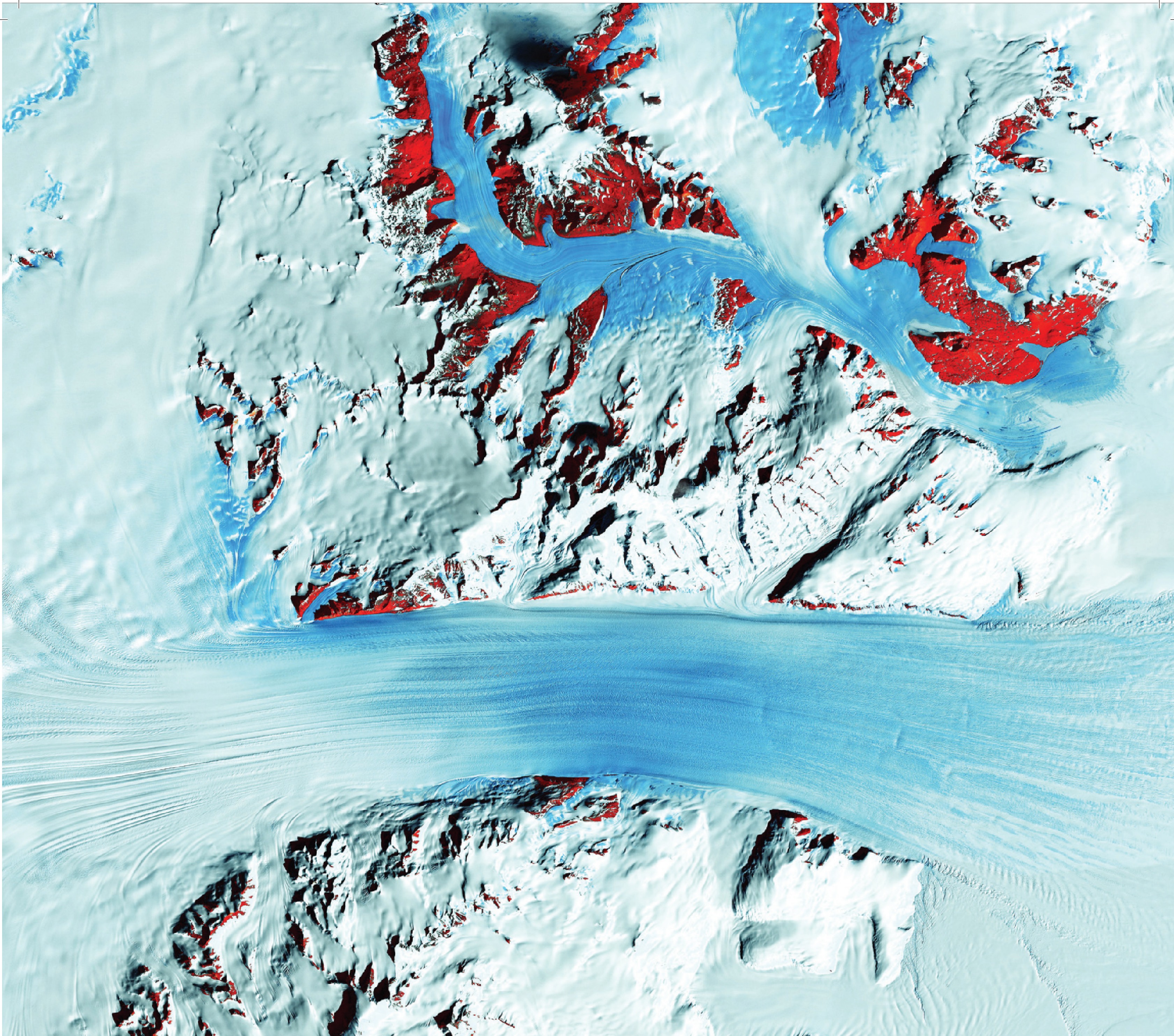
- **LOW CONDUCTANCE SILICON MICRO-LEAK FOR MASS SPECTROMETER INLET**

  Dan Harpold, Hasso Niemann, Bernard Lynch, Brian Jamieson

Patent Applications Filed

- **SPACECUBE DEMONSTRATION PLATFORM**

  David Petrick, Alessandro Geist, Gary Crum, Manuel Buenfil, Jeffrey Hosler, Tom Flatley, Daniel Espinosa



▶ *Landsat image taken of Byrd Glacier.* —PHOTO BY NASA

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